EFFECTS OF VISCOSITY AND TEMPERATURE ON APPLIANCE PERFORMANCE IN RESIDENTIAL OIL COMBUSTION

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INTRODUCTION

A research program on combustion performance evaluation of Canadian middle distillates was carried out at the Combustion and Carbonization Research Laboratory. The program was initiated in response to the needs of the oil industry as well as the standard writing bodies for better fuel quality specifications. The combined effects of industry's effort to maximize the product yield from a crude barrel and the increasing demand on light distillates created the increased use of lower quality products for heating. In Canada, where an abundance of oil sands bitumen and heavy fuels are available, the use of distillates processed from such unconventional sources presents a practical solution to increasing energy demand and declining conventional resources. The effects of these lower quality products on appliance performance must be examined and technologies developed to ensure safe and efficient utilization of the fuels in existing appliances. The standard writing bodies require such information as well to update the existing specifications as required as the quality of the products and the equipment requirements change from time to time. Data from this program are being used to establish correlations fuel properties and combustion characteristics of various Canadian distillate fuels. This paper describes information that demonstrate the effects of fuel viscosity on particulate emissions generated during the transient operation of a residential oil burner.

EXPERIMENTAL SECTION

Fuel variety

Fuel oils were contributed by various Canadian oil companies. The origin of crudes and process vary depending on the company and location. Special blends were prepared in the laboratory to include fuels with a wide range of viscosities. A particular effort was made to keep other variables at a constant value especially aromaticity. All blends contained fuels of different origin and do not necessarily represent the same fuel matrix.

Fuel analysis

Chemical and physical properties of the fuels were determined using standard ASTM techniques. Aromaticities of the fuel were determined by the proton nuclear magnetic resonance (^{1}HNMR) method. The ^{1}HNMR spectra were obtained on a Varian model EM-390 spectrometer operated at 90 MHz. The samples were prepared by mixing the oil with chloroform-d_1 in a 50/50 volume ratio and a drop of Me_4 Si was added as a reference. Aromaticities of the fuels were calculated from hydrogen intensities using the method of Muhl et.al (1).

Combustion experiments

Short term combustion experiments were carried out using the procedure developed at the Combustion and Carbonization Research Laboratory (2). The experimental procedure simulated the actual usage pattern of residential oil heating in Canadian homes. A typical experimental run started with an initial burner startup (cold start) which lasted one hour (steady state), immediately followed by five consecutive 10 minutes on /10 minutes off, cyclic operations. Flue gas emissions and temperatures at specified locations of the test rig were continuously monitored over the entire run. The following experimental equipment and operating conditions were used.

Fuel temperature:	15^{o}C
Nozzle oil temperature:	set as required
Fuel pump pressure:	100 psi
Oil nozzle:	0.75 US gph with 80 spray angle
Combustion air:	Set to obtain a No 2 smoke at steady state
Cold air return temperature:	15 $\pm$ 1 ^{o}C
Burner and retention head:	Beckett burner and Aero AFC2
Furnace:	Forced air type. Brock model LO-1M, 74,000-120,000 Btu/h, with concentric tube type heat exchanger.
Furnace draft:	1 mm (0.04 in) of water column

The fuel temperature was kept constant at 15 ^{o}C in a fuel conditioner that was cooled by a circulating coolant. A thermocouple was inserted into the centre of the nozzle adapter at a closest possible position to the nozzle tip. The oil temperature at discharge was determined using this thermocouple. That temperature was controlled by cooling the combustion chamber and burner with a blast of chilled air. The nozzle temperature was held between 17 and 19^{o}C for all fuels. Each fuel was tested for a minimum of three times and average values were reported.

Measurement of particulate emissions

Particulates, mainly soot, in the flue gas stream were determined using a commercial smoke opacity meter (Celesco model 107). The meter uses a light attenuation principle and is normally used for determining smoke in diesel engine exhaust gases. The instrument was installed vertically, in line with the furnace flue pipe. The opacity % reading from the meter was continuously recorded on a strip chart recorder to capture the entire soot production profile at each transient operation. Area under the peak of each operation was reported as area in square inch per transient cycle.

RESULTS AND DISCUSSION

Fuel variety

Several Canadian oil companies contributed fuels of different origins to this quality evaluation program. These included products from conventional crudes, both Canadian and imported, and synthetic crudes processed from oil sands bitumen and heavy oils. Several special blends had to be prepared in house to obtain fuels with specific qualities. Results have shown that fuel viscosity and aromatics show the strongest influence on oil burner performance (3). This study was dedicated to examine the fuel viscosity effects on combustion performance and required fuels with varying viscosities but with similar aromatic contents. The current CGSB requirement for No. 2 heating fuels is a minimum of 1.4 and a maximum of 3.6 centi stoke or millimetre/second at 40 ^{o}C. Fuels with a range of viscosities 1.8 to 5.1 at 38^{o}C (100^{o}F) were included in this study.

Chemical and physical properties of the fuels

Each fuel was analyzed for aniline point, aromatics, aromaticity, calorific value, cloud point, density, distillation range, flash point, pour point, ramsbottom carbon, viscosity, water and residue, and ultimate analysis using ASTM (American Society for Testing and Materials) and CGSB(Canadian General Standards Board) standard methods. The fluorescent indicator adsorption method (FIA) presents operational problems for fuels with final boiling points higher than 315 ^{o}C and colored fuels in determining the fuel aromatic content. The ^{1}HNMR technique provides the percent ratio of the aromatic carbons to the total number of carbons present in an average molecule that represent a fuel. Table 1 reports some of the analysis data of 15 fuels included in the experimental program.

Particulate emissions from combustion

Performance of fuels are rated in terms of several combustion characteristics including burner ignition behaviour, flame characteristics, potential burner failure, appliance efficiency, heat exchanger corrosion and gaseous and particulate emissions. Poor fuel quality is associated with poor appliance performance and excessive emissions of incomplete combustion products such as particulates, carbon monoxides, and hydrocarbons. Data indicate that carbon monoxide and hydrocarbon emissions exhibit the same trend as particulate emissions. The discussion in this paper is focused on the performance rating as reflected by the generation of particulates.

The commercial smokemeter used was found to be sensitive to particulates equivalent to or higher than smoke number 5, when tested with a commercial Bacharach smoke tester(industry's standard smoke test equipment). The meter has to be especially calibrated for this application.

Results indicate that particulates generated during the cold temperature burner start (cold start) are significantly higher than those from on/off cyclic operations (warm start). This difference is mainly due to the temperature difference at which combustion of the oil takes place. The cold start temperature was set between 17^{o}C and 19 ^{o}C, based on the actual readings found in homes located in central Canada (17 - 24 ^{o}C). The nozzle oil temperature increased to between 45 ^{o}C and 70 ^{o}C during cyclic operations. A significant observation was made in that lower quality fuels generated excessive soot at cold start but produced near normal levels (compared to within-spec heating fuel) at warm start.

Figure 1 shows the smoke opacity profile recorded from a commercial within-spec heating fuel. The first peak represents the cold start and the peak at the end of one hour run represents the burner shutdown. It can be compared to the Figure 2 profile from combustion of a fuel with high aromatics and a viscosity higher than specifications. The duration of time taken for dissipation of soot from the furnace exit also serves as a good indicator of performance. Table 2 represents data from 15 test fuels. As indicated by data in table 1, aromaticity of fuels is reasonably similar with the exception of Fuels 14 and 15. Both have high fuel aromatics but Fuel 14 has higher viscosity(beyond maximum 3.6 c St at 40^{o}C) than Fuel 15 (within-spec). Data in table 2 indicate an increase in both area under the smoke opacity peak and smoke dissipation time with increased fuel viscosity. Figure 3 is the graphical representation. The high value for Fuel 14 resulted from high fuel viscosity as well as high fuel aromatics. However, Fuel 15 exhibits only a higher than normal value (than those from Fuels 3,4,5), despite the fact that it has a similarly high aromatics as in Fuel 14. It appears that higher than spec viscosity can be tolerated provided that fuel aromatics are reasonably low. There is no specific specification for fuel aromatics in place but most of the commercial furnace fuels have below 40 volume percent (about 25% aromaticity). A similar example can be demonstrated using data from Fuels 10 and 11. The fuel density also plays a partial role. Although there is a general positive trend between viscosity and density, the correlation is not always true. If higher than specifications viscosities are to be used, it is essential that both aromatics and density be kept at low levels.

Figure 4 represents the effect of oil temperature at the nozzle on particulate emissions of Fuel 15. It is similar to the viscosity - emission relation, since the oil temperature directly controls the viscosity. It can be compared to Figure 5 showing the viscosity - emission relation of a commercial furnace fuel (Fuel 3). The viscosity of Fuel 3 was determined at different temperatures and a temperature-viscosity calibration line was developed. Particulate emissions of Fuel 3 determined at different cold start combustion temperatures are shown in Figure 5. This fuel was tested to provide information on the cold start behaviour of commercial furnace fuels at cold regions of Canada. There are certain areas of area where the basement temperatures are low enough to have an oil combustion temperature of 5°C. In such cases, the viscosity of a commercial fuel suitable for an average climate could increase to its critical value at which poor combustion will result (3). Data suggests that a fuel with viscosity about 2.5 c St at 38°C could be used in locations where the coldest basement temperature is about 10°C, without any negative effects.

It can be concluded from this study that increasing fuel viscosity has a strong positive influence on incomplete combustion products. The combustion performance of lower grade fuels can be improved and manipulated to advantage if other dominating fuel properties can be controlled.

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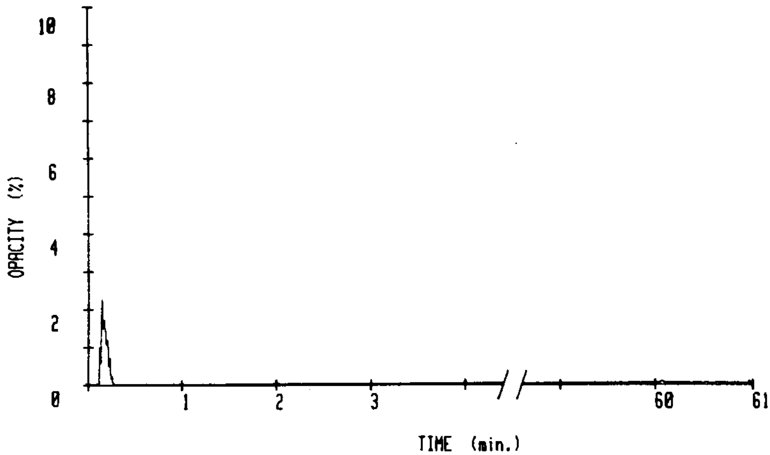

Fig. 1. Opacity profiles of cold start and shut down from a steady sta
furnace fuel

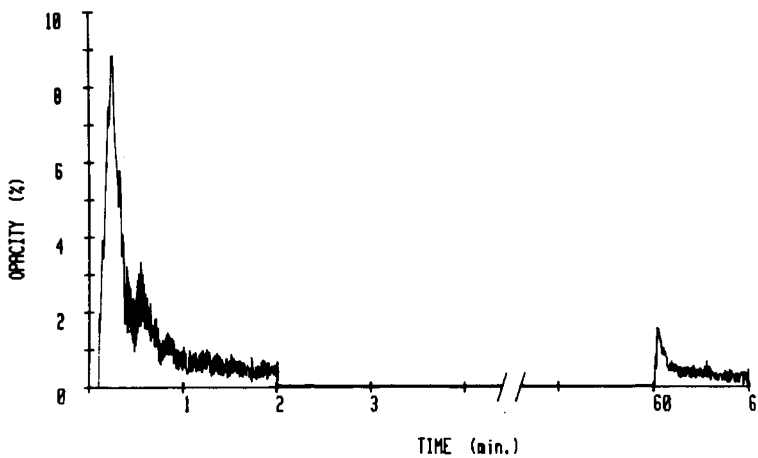

Fig. 2. Opacity profiles of cold start and shutdown from a steady stat
firing a high viscosity, high aromatic fuel.

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Table 1. Fuel variety and properties

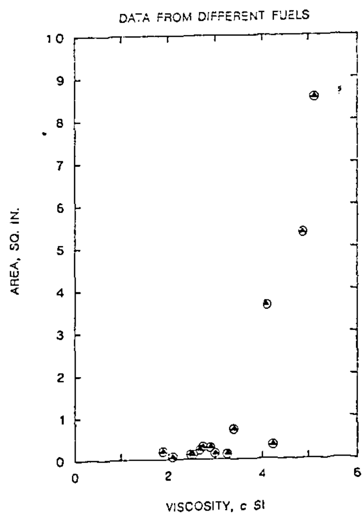
Fuel ID & type	Viscosity, c St @ 38°C	H/C ratio	Aromaticity, % by ^{1}HNMR	Density, kg/L @15°C
1. special blend	1.88	1.806	15	0.840
2. winter diesel	2.09	1.802	16	0.845
3. furnace fuel	2.48	1.782	16	0.844
4. furnace fuel	2.52	1.748	20	0.855
5. furnace fuel	2.68	1.732	21	0.864
6. special diesel	2.90	1.663	24	0.879
7. special blend	3.00	1.712	21	0.864
8. light gas oil	3.26	1.798	21	0.860
9. special blend	3.39	1.744	23	0.864
10. special blend	4.09	1.746	18	0.872
11. special blend	4.24	1.766	11	0.881
12. special blend	4.87	1.768	11	0.883
13. special blend	5.12	1.740	18	0.884
14. light cycle oil	3.60	1.378	40	0.926
15. special blend	2.74	1.406	42	0.923

Table 2. Particulate emissions from fuels with different viscosities

Fuel	Viscosity, c St @ 38°C	Area [1] sq.in.	Time [2] sec
1.	1.88	0.21	15
2.	2.09	0.08	12
3.	2.48	0.15	22
4.	2.52	0.13	24
5.	2.68	0.26	29
6.	2.90	0.31	44
7.	3.00	0.16	12
8.	3.26	0.16	42
9.	3.39	0.73	55
10.	4.09	3.65	180
11.	4.24	0.35	120
12.	4.87	5.36	325
13.	5.12	8.56	465
14.	3.60	52.30	750
15.	2.74	0.31	44

[1]. area under the opacity peak
[2]. Time for smoke to dissipate

Fig. 3. The effects of visco on particulate emissions



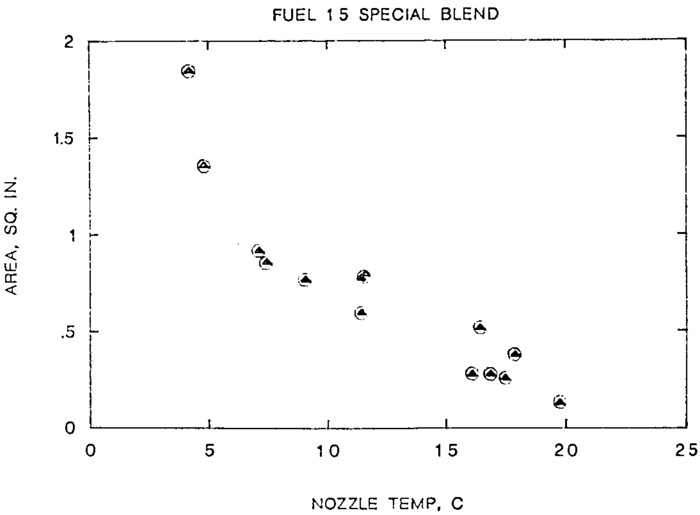


Figure 4. Effect of temperature on particulate emissions. Fuel 15.

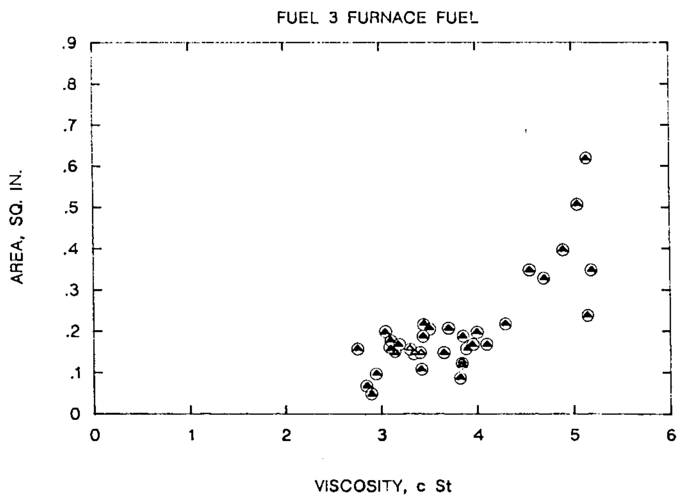


Figure 5. Effect of viscosity on particulate emissions. Fuel 3.